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Original Article

# Does nighttime exercise really disturb sleep? Results from the 2013 National Sleep Foundation Sleep in America Poll

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ABSTRACT

*Objective:* To assess the relationship between sleep, time of exercise, and intensity of exercise in a large American sample.
*Methods:* The 2013 National Sleep Foundation Sleep in America Poll was a cross-sectional study of 1000 adults stratified by age (23–60 years) and US geographical region. Sleep outcomes included self-reported sleep quality, total sleep time, sleep latency, and waking unrefreshed. Exercise timing was characterized as morning (>8 h before bed), afternoon (4–8 h before bed), or evening (<4 h before bed). Exercise intensity was assessed with a modified version of the International Physical Activity Questionnaire.
*Results:* After adjustment for confounders, evening moderate or vigorous exercisers did not differ in any of the reported sleep metrics compared to non-exercisers. Morning vigorous exercisers had the most favorable sleep outcomes, including greater likelihood of reporting good sleep quality (OR = 1.88, $p < .001$) and lower likelihood of waking unrefreshed (OR = 0.56, $p = .03$). Most individuals who performed vigorous evening exercise believed that their sleep was of equal or better quality (97%) and duration (98%) on days they exercised.
*Conclusion:* Evening exercise was not associated with worse sleep. These findings add to the growing body of evidence that sleep hygiene recommendations should not discourage evening exercise.


## 1. Introduction

Experts widely advocate routine exercise for improving sleep quality. As a primary recommendation, exercising regularly is incorporated into standard "sleep hygiene" advice [1]. However, this recommendation is typically presented with the caveat that one should avoid exercising near bedtime. This warning concerning the timing of exercise with respect to bedtime is endorsed by sleep medicine experts [2,3] and lay media [4,5].

It is speculated that exercise near bedtime could disrupt sleep by altering circadian phase [6], elevating core body temperature [7], or increasing physiological arousal [8]. However, the few available experimental studies [9–11] and surveys [12,13] addressing this issue have generally failed to substantiate such concerns that evening exercise negatively impacts sleep. In fact, arguments could be made that evening might be the optimal time for exercise-related sleep benefits based on findings that decreases in self-reported anxiety and in physiological indices of anxiety such as blood pressure and muscle tension are most evident 1–2 h following exercise [14]. Moreover, people tend to fall asleep when body temperature is rapidly declining [7], which is also most evident following exercise.

The extant literature sheds little light on this subject because methodological and sampling issues limit generalization. Missing and/or incomplete specifications about exercise intensity and narrowly defined sample characteristics diminish broad interpretability. Many experimental studies exploring the exercise timing-sleep relationship only included good sleepers [9–11] and/or individuals who were accustomed to regular exercise [10,11].

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The proper (or improper) timing of exercise with respect to sleep is an important public health issue. Exercise has well-established benefits for longevity and disease prevention [15], yet most Americans receive much less exercise than needed to realize these benefits [16]. Lack of time is the most commonly cited barrier to regular exercise [17], and individuals may find it difficult to schedule exercise at times other than within a few hours of bedtime. Consequently, discouraging evening exercise may have the unintended consequence of reducing or eliminating exercise altogether for some individuals. Therefore, the purpose of this study was to examine the relationship between sleep, exercise intensity, and exercise timing (morning, afternoon, evening) in a large American sample that participated in the National Sleep Foundation's 2013 *Sleep in America* (SIA) poll. Specifically, we examined whether individuals who exercised in the evening reported more disturbed sleep relative to non-exercisers.

## 2. Methods

### 2.1. Poll content

The poll content was developed by a task force of independent scientists and clinicians. Members were invited based on their expertise in sleep science/medicine and/or exercise science. Poll items were derived from several sources including validated questionnaires (used either in part or in their entirety) and items developed specifically for the poll. A core set of questions used annually in SIA polls were included to examine trends in sleep habits over time. Task force members made final decisions concerning specific item inclusion/exclusion. A complete listing of questions used for the poll can be found at www.sleepfoundation.org/2013poll. The National Sleep Foundation did not solicit or accept any corporate support for this poll.

### 2.2. Procedures

Telephone interviews were conducted by professional interviewing staff of WB&A Market Research (Crofton, MD) using a computer-assisted telephone interviewing system to provide a script prompt and tabulate responses. The telephone sample used random digit dialing of listed and cell phone numbers. The web sample was obtained using an online E-Rewards panel of Americans meeting study requirements. Upon completion, interviews were edited, coded and keypunched. Data were collected from October 19 to November 12, 2012. Institutional review board approval is not required to conduct or publish results of a poll without identifying information that is conducted by a non-profit independent organization.

### 2.3. Sample

The sample used was composed of individuals currently living in the United States. Surveys were collected from 1000 individuals, 23–60 years of age. By design, half of the data ($n$ = 500) were collected via a telephone interview, and half of the data ($n$ = 500) were collected by a web-based system. The sample was stratified by age and geographical US region. Sample size for stratification on these factors was derived from 2010 United States Census data. Maximum sampling error for the entire sample was ±3.1% (at the 95% confidence level).

### 2.4. Measures

#### 2.4.1. Sample characteristics

All data included in this report were self-reported and administered concurrently. Characteristics of interest included age, ethnicity (Hispanic/Latino vs. Not Hispanic/Latino), race (White, Black, Asian, Biracial, Other), employment (full- or part-time), education (high school diploma or less, some college/Associate's degree, 4-year college degree or more), marital status (married/partnered vs. other), US geographic region (Northeast, Midwest, South, West), and body mass index (BMI; kg/m$^2$ from weight [kg] and height [m]).

#### 2.4.2. Exercise behavior

Exercise behavior was measured via a modified International Physical Activity Questionnaire [18] to assess activity in the past 7 days that was vigorous ("hard physical effort…including running, cycling, swimming, and competitive sports"), moderate ("moderate physical effort…including carrying light loads, yoga, tai chi, and weight lifting [not walking]"), and light ("light physical activity…including yard work at home, walking for recreation, sport, exercise, or leisure"). Participants were able to respond to each question of exercise intensity separately to allow individuals to endorse multiple activities they regularly perform that fit into different intensity categories. Each intensity question (if endorsed) was followed by a question assessing the typical time of day this activity was performed: (a) >8 h before bedtime ("morning"); (b) 4–8 h before bedtime ("afternoon"); or (c) <4 h before bedtime ("evening"). These items were combined such that each individual could independently be classified as a morning, afternoon, or evening exerciser of vigorous, moderate, and light intensities.

#### 2.4.3. Sleep measures

Almost all of the sleep quality/duration metrics were assessed in reference to the past 2 weeks. Overall sleep quality was measured with one 4-item Likert-type question with 'very good,' 'fairly good,' 'fairly bad,' and 'very bad' response options. For analysis, responses were collapsed to good (fairly good/very good) vs. poor (fairly bad/very bad) sleep quality. Total sleep time (TST) was assessed in hours and minutes "on average worknights or weeknights…not including naps." For analysis, TST values were collapsed to optimal TST (7–8.5 h) vs. non-optimal TST (<7 h or >8.5 h). Sleep onset latency (SOL) was assessed in "minutes, on most worknights or weeknights…to fall asleep." For analysis, SOL values were collapsed to long SOL ($\geqslant$15 min) vs. short SOL (<15 min). Waking up feeling unrefreshed was assessed with one 4-item Likert-type question with 'every night or almost every night,' 'a few nights a week,' 'rarely,' and 'never' response options. For analysis, responses of 'every night or almost every night' and 'a few nights a week' were combined to indicate difficulty waking up feeling unrefreshed. Finally, the belief that exercise impacts sleep following exercise was assessed with one question (with no stated timeframe) in which respondents indicated whether they believed that exercise "improved," "worsened," or "made no difference" for their sleep.

### 2.5. Analysis

Gender-specific descriptive analyses were used to examine sample differences by study covariates and exercise and sleep variables. Multiple logistic regression analysis (SAS Enterprise Guide 5.1; SAS Institute, Inc., Cary, NC) was used to identify independent predictors of the sleep variables (sleep quality, TST, SOL, and

waking up unrefreshed). Exercise timing (morning, afternoon, evening, none) as an independent predictor was tested in separate models for vigorous, moderate, and light exercise. We explored effect modification of the exercise timing-sleep quality/duration relationship by BMI (entered continuously) and gender. All models were adjusted for age, gender, ethnicity, race, employment, education, marital status, geographical region, BMI, and method of survey administration (web, telephone). Finally, we performed $X^2$ goodness of fit tests among evening vigorous exercisers to examine beliefs about whether exercise improved, worsened, or made no difference with respect to sleep quality and duration on nights following exercise. We also examined this relationship among good and poor sleepers using the same dichotomy for overall sleep quality previously discussed (good [fairly good/very good] vs. poor [fairly bad/very bad] sleep quality). Statistical tests were conducted at the $p < 0.05$ significance level unless otherwise noted.

## 3. Results

### 3.1. Demographic, exercise, and sleep variables

Table 1 provides sample demographics by gender for the sample of 1000 respondents. The sample was primarily middle-aged, non-Hispanic White, working, college-educated, married/partnered, and overweight. Men were older and were more likely to work, have 4-year college degree or more, and have a higher BMI than women.

Table 2 provides descriptive physical activity, sleep quality and duration metrics by gender. Men were more likely to report afternoon vigorous and moderate exercise. Women reported worse sleep than men, with an increased likelihood of waking unrefreshed, "very bad" sleep quality, and longer SOL. The vast majority of respondents believed that exercise either improved or made no difference for sleep.

### 3.2. Logistic regression analyses: exercise timing and sleep

Table 3 summarizes results of logistic regression analyses for sleep quality and duration by the time of day that respondents reported that they exercised. Evening exercisers did not differ from non-exercisers (referent group) in any sleep quality or duration metric, with the exception of TST, for which evening light exercisers were more likely to report having optimal TST than non-exercisers. Morning vigorous and moderate exercisers had the most favorable overall sleep quality. Exercise timing had no association with SOL. Morning vigorous and light exercisers were less likely to report difficulty waking up unrefreshed than non-exercisers.

### 3.3. Effect modification of BMI and gender

BMI was not a significant effect modifier in any of the logistic regression models, suggesting that the exercise time of day-sleep relationship was similar across BMI levels. Gender was a significant moderator in some models. Men who were morning vigorous (92%) and light (87%) exercisers were more likely to report good sleep quality than their women vigorous (73%) and light (70%) counterparts (Fig. 1). However, women evening exercisers (23%) were less likely to wake up feeling unrefreshed than their male (30%) counterparts (Fig. 2).

### 3.4. Vigorous evening exerciser sub-analysis: sleep quality and duration

Figs. 3 and 4 display beliefs about the impact of exercise on sleep quality and duration, respectively, among individuals who exercised vigorously in the evening. Only 3% of vigorous evening exercisers reported that they felt their sleep was worse after exercise, whereas 40% and 57% reported that their sleep was not

**Table 1**
National Sleep Foundation Sleep in America Poll 2013 sample demographics by gender ($N = 1000$).

| | Men | Women | Total |
|---|---|---|---|
| | *N* (%) | *N* (%) | *N* (%) |
| *N* | 484 (48.40) | 516 (51.60) | 1000 (100.00) |
| Age, M ± SD | 42.98 ± 11.29[a] | 41.00 ± 10.92 | 41.95 ± 11.14 |
| 23–29 | 74 (15.29) | 103 (19.96)[b] | 177 (17.70) |
| 30–39 | 129 (26.65) | 137 (26.55) | 266 (26.50) |
| 40–49 | 122 (25.21) | 150 (29.07) | 272 (27.20) |
| 50–60 | 159 (32.85)[a] | 126 (24.42) | 285 (28.50) |
| Hispanic/Latino ethnicity | 24 (5.01) | 36 (7.03) | 60 (10.10) |
| *Race* | | | |
| White | 383 (80.97) | 405 (79.72) | 788 (80.33) |
| Black | 36 (7.61) | 46 (9.06) | 82 (8.36) |
| Asian | 29 (6.13) | 18 (3.54) | 47 (4.79) |
| Other | 25 (5.29) | 39 (7.68) | 64 (6.52) |
| Full-time/part-time work status | 406 (84.23)[a] | 362 (70.16) | 768 (76.95) |
| *Education* | | | |
| High school diploma or less | 67 (13.93) | 78 (15.18) | 145 (14.57) |
| Some college/Associate's degree | 124 (25.78) | 170 (33.07) [b] | 294 (29.55) |
| 4-year college degree or more | 290 (60.29)[a] | 266 (51.75) | 556 (55.80) |
| Married/partnered | 324 (67.94) | 321 (62.57) | 645 (65.02) |
| *Geographic region* | | | |
| Northeast | 89 (18.39) | 89 (17.25) | 178 (17.80) |
| Midwest | 110 (22.73) | 107 (20.74) | 217 (21.70) |
| South | 172 (35.54) | 201 (38.95) | 373 (37.30) |
| West | 113 (23.35) | 119 (23.06) | 232 (23.20) |
| Body mass index, M ± SD | 27.85 ± 5.25[a] | 26.80 ± 6.17 | 27.32 ± 5.76 |
| Underweight | 2 (0.43) | 12 (2.49)[b] | 14 (1.47) |
| Normal | 136 (28.94) | 223 (46.27)[b] | 359 (37.71) |
| Overweight | 205 (43.62)[a] | 122 (25.31) | 327 (34.35) |
| Obese | 127 (27.02) | 125 (25.93) | 252 (26.47) |

[a] Men higher than women, $p < .05$.
[b] Women higher than men, $p < .05$.

**Table 2**
Descriptive physical activity[†] and sleep quality and duration metrics by gender.

| | Men | Women | Total |
|---|---|---|---|
| | *N* (%) | *N* (%) | *N* (%) |
| *Vigorous exercise* | | | |
| Morning | 123 (25.95) | 127 (25.05) | 250 (25.48) |
| Afternoon | 131 (27.64)[a] | 101 (19.92) | 232 (23.65) |
| Evening | 65 (13.71) | 65 (12.82) | 130 (13.25) |
| None | 155 (32.70) | 215 (42.41) | 369 (37.61) |
| *Moderate exercise* | | | |
| Morning | 138 (28.81) | 144 (28.24) | 282 (28.51) |
| Afternoon | 161 (33.61)[a] | 132 (25.88) | 293 (29.63) |
| Evening | 46 (9.60) | 57 (11.18) | 103 (10.41) |
| None | 134 (27.97) | 175 (34.31) | 311 (31.45) |
| *Light exercise* | | | |
| Morning | 174 (36.86) | 208 (40.94) | 382 (39.02) |
| Afternoon | 168 (35.59) | 179 (35.24) | 347 (35.44) |
| Evening | 65 (13.77) | 82 (16.14) | 147 (15.02) |
| None | 64 (13.56) | 39 (7.68) | 113 (10.52) |
| *Overall sleep quality* | | | |
| Very good | 106 (21.90)[a] | 84 (16.28) | 190 (19.00) |
| Fairly good | 289 (59.71) | 280 (54.26) | 569 (56.90) |
| Fairly bad | 75 (15.50) | 117 (22.67)[b] | 192 (19.20) |
| Very bad | 14 (2.89) | 35 (6.78)[b] | 49 (4.90) |
| *Total sleep time* | | | |
| <7 h | 201 (41.53) | 212 (41.09) | 413 (41.30) |
| 7–8.5 h | 268 (55.37) | 267 (51.74) | 535 (53.50) |
| >8.5 h | 15 (3.10) | 37 (7.17)[b] | 52 (5.20) |
| *Sleep onsent latency* | | | |
| <15 min | 311 (64.26)[a] | 266 (51.55) | 577 (57.70) |
| 15–30 min | 100 (20.66) | 103 (19.96) | 203 (20.30) |
| >30 min | 73 (15.08) | 147 (28.49)[b] | 220 (22.00) |
| *Waking up feeling un-refreshed* | | | |
| Almost every night | 89 (18.54) | 154 (30.02)[b] | 243 (24.47) |
| A few nights a week | 149 (31.04) | 201 (39.18) | 350 (35.25) |
| Rarely | 182 (37.92)[a] | 122 (23.78) | 304 (30.61) |
| Never | 60 (12.50)[a] | 36 (7.02) | 96 (9.67) |
| *Belief exercise impacts sleep* | | | |
| Improves | 259 (56.43) | 250 (50.20) | 509 (53.19) |
| Worsens | 11 (2.40) | 11 (2.21) | 22 (2.30) |
| No difference | 189 (41.18) | 237 (47.59) | 426 (44.51) |

[†] Vigorous, moderate, and light exercise intensities were assessed independently to allow respondents to endorse multiple intensities.
[a] Men higher percentage than women, $p < .05$.
[b] Women higher percentage than men, $p < .05$.

**Table 3**
Logistic regression results for sleep quality and duration outcomes for morning, afternoon, and evening exercisers compared to nonexercisers (referent) ($N = 1000$).

| | Good sleep quality (75.9%) | | Optimal TST (53.5%) | | Long SOL (42.3%) | | Waking unrefreshed (59.7%) | |
|---|---|---|---|---|---|---|---|---|
| | b (se) | OR | b (se) | OR | b (se) | OR | b (se) | OR |
| *Vigorous exercise* | | | | | | | | |
| Morning | 0.63 (0.22) | 1.88*** | 0.17 (0.18) | 1.19 | −0.20 (0.18) | 0.82 | −0.58 (0.22) | 0.56** |
| Afternoon | 0.25 (0.21) | 1.28 | 0.05 (0.18) | 1.05 | −0.15 (0.18) | 0.86 | −0.25 (0.21) | 0.78 |
| Evening | 0.57 (0.26) | 1.06 | 0.05 (0.23) | 1.05 | −0.14 (0.23) | 0.87 | −0.07 (0.26) | 0.94 |
| None | (ref) | | (ref) | | (ref) | | (ref) | |
| *Moderate exercise* | | | | | | | | |
| Morning | 0.43 (0.20) | 1.53* | 0.30 (0.18) | 1.35 | −0.18 (0.18) | 0.84 | −0.20 (0.20) | 0.82 |
| Afternoon | 0.34 (0.20) | 1.41 | 0.20 (0.18) | 1.23 | −0.19 (0.18) | 0.83 | −0.29 (0.21) | 0.75 |
| Evening | 0.12 (0.28) | 1.13 | 0.31 (0.25) | 1.36 | −0.23 (0.25) | 0.79 | −0.23 (0.29) | 0.79 |
| None | (ref) | | (ref) | | (ref) | | (ref) | |
| *Light exercise* | | | | | | | | |
| Morning | 0.51 (0.23) | 1.66 | 0.42 (0.25) | 1.52 | −0.18 (0.25) | 0.84 | −0.60 (0.28) | 0.55* |
| Afternoon | 0.37 (0.28) | 1.45 | 0.59 (0.25) | 1.80 | −0.03 (0.26) | 0.97 | −0.30 (0.28) | 0.74 |
| Evening | 0.34 (0.32) | 1.41 | 0.57 (0.29) | 1.77* | −0.04 (0.29) | 0.96 | −0.17 (0.32) | 0.84 |
| None | (ref) | | (ref) | | (ref) | | (ref) | |

Models are adjusted for age, gender, ethnicity, race, work status, educational status, marital status, geographical region, BMI, and web vs. telephone-administration.
* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

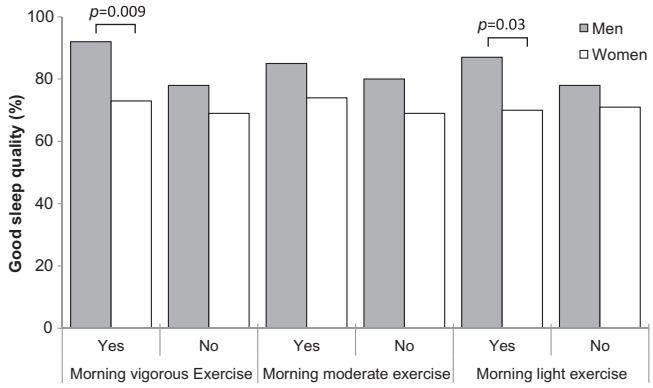


**Fig. 1.** Sleep quality among morning vigorous, moderate, and light exercisers by gender.

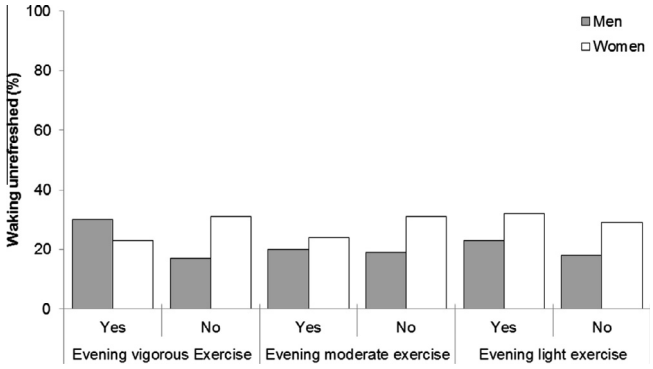


**Fig. 2.** Likelihood of waking unrefreshed among evening vigorous, moderate, and light exercisers by gender.

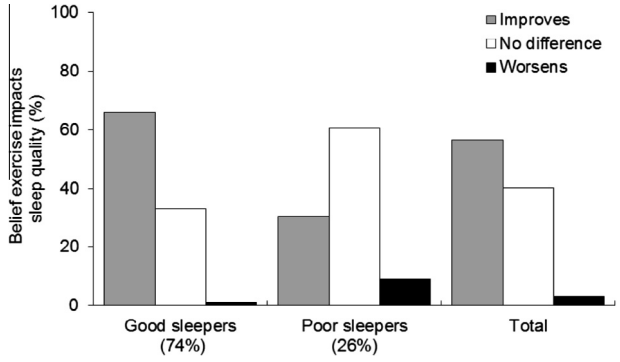


**Fig. 3.** Belief that exercise impacts sleep quality on nights following exercise among evening vigorous exercisers by reported sleep quality.

different or improved, respectively ($X^2 = 57.28$, $p = 0.001$). Even among respondents who reported poor sleep quality, only 9% reported that their sleep was worse after exercise, whereas 61% and 30% reported that their sleep was not different or improved, respectively. Likewise, among vigorous evening exercisers, only 2% reported worse sleep duration, whereas 68% and 30% reported sleep duration was not different, or improved respectively ($X^2 = 83.45$, $p < 0.001$). Among vigorous evening exercisers who reported poor sleep quality, 3% reported worse sleep duration after exercise, whereas 88% and 9% reported sleep duration was not different or improved, respectively ($X^2 = 44.36$, $p < 0.001$).

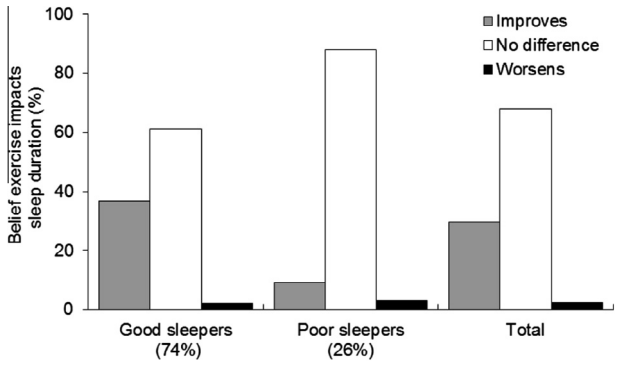


**Fig. 4.** Belief that exercise impacts sleep duration on nights following exercise among evening vigorous exercisers by reported sleep quality.

## 4. Discussion

Traditional sleep hygiene recommendations suggest that regular exercise facilitates sleep. However, individuals are cautioned to avoid exercise (especially vigorous exercise) near bedtime. Results from this study supported the connection between exercise and better sleep, but failed to confirm the contention that exercising near bedtime is associated with disturbed sleep.

The positive relationship between exercise and sleep is consistent with previous survey findings [12,13], including a large nationally-representative study using objective measures of physical activity [19] and a recent study of adolescents examining relationships between exercise and sleep using both objective and self-reported methods of physical activity and sleep [20]. Experimental studies have also shown sleep improvement following acute exercise and exercise training [21,22].

What time of day of exercise is most associated with better sleep has been less well-established. An earlier meta-analysis found that acute exercise in the afternoon was more likely to elicit improvements in sleep than exercise in the morning or evening [23]. Conceivably, the time of day of regular exercise could also influence sleep chronically. For example, more so than acute exercise, chronic exercise and associated light exposure in the morning and evening could advance and delay the circadian system, respectively. In the present study, the report of customary morning exercise was more strongly associated with better sleep than exercise at other times. This is consistent with a recent experimental study of adolescents performing 3 consecutive weeks of morning exercise showing improved objective and self-reported sleep [24].

However, it is noteworthy that the present analyses revealed that evening exercise (ie performed within 4 h of bedtime) was not associated with any measure of disturbed sleep. Indeed, individuals who reported performing vigorous exercise in the evening were significantly less likely to wake up feeling unrefreshed than those who did not report vigorous exercise. Moreover, the vast majority of evening exercisers believe that they slept better or no different after exercise. These results are consistent with the majority of the literature that has addressed this question. Previous epidemiologic findings have indicated that a majority of individuals exercising 0–2 h before bedtime felt that evening exercise helped them fall asleep and sleep more soundly [12]. Similarly, acute experimental studies have not observed sleep disturbances following evening exercise compared to non-exercise conditions in most subjects [10,11,25]. This relationship has held true even when exercise ended just 30 min before bedtime [11,25]. In fact, in some studies, sleep improved following evening exercise [9,26–28].

Notwithstanding evidence to the contrary, the sleep hygiene recommendation to avoid evening exercise remains in the popular press as well as in position statements published by sleep societies [29]. The persistence of this notion might be partly explained by the fact that it may disturb sleep for a small minority of individuals. However, these findings may redress some of the fears poor sleepers may have regarding nighttime exercise which may, ironically, indeed result in poor sleep. It should be noted, however, that our results suggested the vast majority of poor sleepers reported improved or no difference in sleep after nighttime exercise.

There are also theoretical rationales behind sleep-impairing assumptions about evening exercise, but they are not well-supported. An often-cited sleep concern regarding late-night exercise posits that autonomic or central nervous system arousal after exercising could interfere with sleep. Studies have found higher heart rate at bedtime following evening exercise; however, sleep onset was not delayed in these trials and heart rate was not correlated with sleep [8,10,11]. Moreover, decreases in state anxiety and psychophysiological indices of anxiety/arousal (e.g., blood pressure and muscle tension) are well-documented at 20 min to a few hours following exercise [30].

The position that temperature elevation following exercise is a barrier to sleep rests on shaky theoretical grounds. Whereas exercise-induced increase in core body temperature occurs, the subsequent thermal dissipation via distal vasodilatation might provide a potent trigger for sleep onset and deep sleep. The preoptic area of the anterior hypothalamus has both sleep/wake and thermoregulatory functions [31] and passive body heating has been shown to significantly reduce sleep onset latency [32]. Although this thermogenic mechanism was best supported by classical studies by Horne and colleagues in which exercise was performed several hours before bedtime [33], the mechanism might be stronger with exercise closer to bedtime.

Compared with other surveys, this survey had several strengths, including a relatively large sample size that was stratified by age and US geographical region, and delivered by phone and Internet mediums, suggesting greater generalization to the population. We were also able to control for a number of potential confounds known to impact exercise behavior, its timing, and sleep.

However, there were also several limitations of the study. First, the cross-sectional nature of this study does not allow conclusions regarding the direction of the influence between exercise and sleep. Indeed, recent studies suggest the potential for reciprocal relationships between exercise and sleep [34,35]. For example, the finding of better sleep for morning exercisers could be explained by a greater propensity for morning exercise after sleeping well. Another limitation was that we did not oversample poor sleepers. One might not expect good sleepers to suffer sleep disruption related to evening exercise. Individuals suffering from insomnia might have more fragile sleep or lower arousal thresholds for autonomic activation or arousal. In this regard, a noteworthy finding in the present study was that the vast majority of poor sleepers indicated that vigorous evening exercise had a beneficial or no effect on sleep quality and duration. Although these results need prospective experimental confirmation, these data suggest that evening exercise does not adversely affect even individuals with poor sleep quality.

Other limitations of the present study include our survey methodology, inadvertent incorporation bias produced by the method, and not having an index for weekly amounts of light, moderate, and vigorous exercise. We administered the survey by phone and internet. While potentially a strength given the enhanced reach with the tandem methods, it likely produced significant heterogeneity among respondents. For instance, telephone-surveyed respondents tended to be older than internet-surveyed participants. Although we statistically adjusted for the mode of survey administration, residual bias may have remained. Furthermore, study demographics were not specifically designed to provide a fully representative US population sample but rather to horizontally distribute across certain factors such as geographic region and age. Thus, sampling issues limit the generalizability of the results.

As with all surveys, we relied on self-report. Consequently, accuracy of our measures for sleep and physical activity remain unknown. Bias also can enter when respondents know a survey's focus. Because it is commonly assumed that exercise leads to better sleep, some of the findings might partly reflect this bias [36]. However, since evening exercise is widely believed to adversely affect sleep, such bias would have worked against the findings which are the main focus of this study. It is worth noting that the survey script did not inform respondents that exercise and sleep was the theme of the poll and questions concerning sleep were separated from those addressing exercise habits, with the exception of a few items at the end of the interview, on which respondents were specifically inquired about how they perceived their sleep to be following exercise. However, there could have been self-selection bias in which individuals either performed or avoided evening exercise depending on whether they experienced no difficulties or sleep disruption, respectively.

In summary, among a large sample of adults, the timing of exercise was significantly associated with sleep quality and duration. In general, morning exercisers were most likely to report good sleep quality and optimal sleep duration and least likely to awaken unrefreshed. Thus, morning exercise may be an optimal time for regular exercise with respect to sleep quality. However, evening exercising was not associated with disturbed sleep, even among those who identified themselves as poor sleepers. These data suggest that, with respect to good sleep, it is better to exercise than not exercise, even if the only time to exercise is close to bedtime.

## Conflict of interest

The ICMJE Uniform Disclosure Form for Potential Conflicts of Interest associated with this article can be viewed by clicking on the following link: http://dx.doi.org/10.1016/j.sleep.2014.01.008.

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